NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2676

SUMMARY OF STALL-WARNING DEVICES

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Washington
May 1952

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SUMMARY

The principles involved in the operation of several types of stall-warning devices are described and conditions under which difficulty may be experienced are pointed out. In the discussion, stall-warning devices are grouped as special stall-sensing devices and angle-of-attack-sensing devices. Methods of transmitting the warning to the pilot are also discussed. Some specific examples of stall-warning devices are illustrated and described.

INTRODUCTION

Under certain flight conditions, such as landing or accelerated maneuvers, the pilot may be forced to fly as close to maximum lift as possible in order to effect a desired change in airplane path. Since stall and its attendant changes in attitude are to be avoided, the pilot must have some indication of the proximity of stall. A few airplanes do have adequate aerodynamic stall warning in the form of wing or tail buffeting which is apparent to the pilot through shaking of the entire airplane structure, the stick, or the rudder pedals. For airplanes that have little or no aerodynamic warning, the use of an artificial stall-warning device appears to be one solution (although perhaps not the most desirable).

Numerous devices have been proposed over the past 25 years in an attempt to provide a satisfactory warning of the impending stall of an airplane. In order to be generally acceptable a stall-warning device must meet rather stringent requirements. The device must provide a consistent margin of warning not only under various flight conditions such as airspeed, wing loading, power setting, and airplane configuration but also under icing conditions. With schemes involving only a single-warning stage, a constant margin of warning, between 5 and 20 percent of the stalling speed (depending on the particular airplane), has been considered desirable. The device, in addition, must be exceptionally reliable. For example, the reliability of an airspeed installation is envisioned by some operators as a practical goal.

Because of the difficulty of satisfying all these requirements, a compromise is sometimes made to accept satisfactory operation of a stall-warning device under limiting conditions, generally the landing condition in absence of icing.

While a variety of stall-warning devices are available, most of the devices operate on a few basic principles. The purpose of this paper is to describe the principles involved in several types of special stall-sensing devices and angle-of-attack-sensing devices and to point out some conditions under which difficulty may be experienced. Some methods of transmitting the warning to the pilot are also discussed and a few examples of special stall-sensing devices and angle-of-attack-sensing devices are given.

PRINCIPLES INVOLVED IN STALL-WARNING DEVICES

Special stall-sensing devices.- Special stall-sensing devices usually operate on flow characteristics associated either with the movement of the stagnation point or with flow separation on the wing. Those devices based on the movement of the stagnation point make use of either the large change in pressure or the 180° change in flow direction as the stagnation point moves past a given position on the wing leading edge. The change in pressure can be detected by means of one or more static-pressure orifices. The change in flow direction can be determined by means of a small pitot-static tube, a free-floating vane, or by reversal of aerodynamic force on a small body placed close to the leading edge. The location of the sensing device relative to the position of the stagnation point at stall determines the margin of warning that is provided.

Devices that operate on the basis of flow separation near the leading or trailing edge make use of the decrease in local velocity, total pressure, or aerodynamic force on a small body near the surface of the wing as stall is approached. Since the spanwise position at which separation occurs initially varies with flight condition and airplane configuration, several such sensing devices distributed over the span are required to give adequate warning. The use of a single unit to sense stall is made possible, however, by artificially inducing separation to occur at a given spanwise station at the desired margin of warning (angle of attack or speed).

Leading-edge devices, in general, operate on larger changes in pressure or aerodynamic forces for small changes in airplane speed near stall than do devices located near the trailing edge (fig. 1). The margin of warning provided by leading-edge devices, therefore, may be expected to have the advantage of being less sensitive to small changes in the details of the device, in wing contour, or in reference pressures.

Since flow separation and the position of the stagnation point are related to angle of attack, the margin of warning provided by sensing devices based on these principles may be affected to some extent by trailing-edge-flap deflection and engine power. In the case of partial-span trailing-edge flaps the effect of the flaps may be minimized and perhaps eliminated by locating the devices, when possible, outboard of the flaps. With full-span leading-edge slats the margin of warning provided by leading-edge devices, if such installations were practical, would probably be affected by slat extension. On some propeller-equipped airplanes the maximum lift coefficient is appreciably affected by application of power. In such cases the margin of warning in terms of angle of attack as provided by a single sensing device may not change with power but the margin in speed above stalling speed may be appreciably increased. One scheme of eliminating the effect of power on the speed margin makes use of a second sensing device located within the propeller slipstream on the wing behind the down-going propeller blade which decreases the local angle of attack. The resulting later actuation of this second unit when power is applied is used to delay the warning signal of the first unit.

Ice formation on the leading edge is expected not only to change the sequence of stall of the various spanwise sections but also to change the angle of attack and lift coefficients at which stall occurs. The relation between the position of the stagnation point, leading-edge separation, and angle of attack would obviously be altered. Devices sensing separation near the trailing edge, however, may still be useful with ice formation on the leading edge provided the devices (several distributed over the span) are heated to prevent ice formation on them.

Angle-of-attack-sensing devices.- An angle-of-attack-sensing device measures the angle of local flow relative to an arbitrary reference line. A device of this type may consist of a vane pivoted in such a way as to aline itself with the local flow or of a pressure head equipped with a pair of orifices or slots symmetrically disposed and a positioning mechanism to maintain zero pressure differential. A fixed pressure head could also be used but would require a pressure-ratio meter similar to the Mach meters now in use in order to provide an indication of the ratio of pressure differential to dynamic pressure and hence of the local flow angle.

The problems associated with the effects of power, airplane configuration, and icing on stall warning mentioned previously in connection with the special stall-sensing devices also apply to angle-of-attack-sensing devices. In addition, consideration must be given to the effect of pitching velocity on the measure of angle of attack when locations forward of the fuselage nose or wing are used and to the effect of the bending of the support in accelerated maneuvers. In the null-pressure type of angle-of-attack-sensing devices there may be a tendency for the

head to hunt about the null point. Such a characteristic is objectionable if the amplitude corresponds to an appreciable margin of warning in speed. Some difficulty may also arise in accelerated maneuvers if the lag of positioning mechanism is large.

Forms of stall warning.- Stall warnings may be transmitted to the pilot by any one of several methods based on sight, hearing, or sense of feel. The visual methods include lights and dial indicators; various combinations and colors of light have been suggested and used in the past. Unless the lights are near the direct line of sight, experience has indicated that the warning may be disregarded. When located in or near the direct line of sight, however, the lights should not be so bright as to interfere with the pilot's view through the windshield and of the flight panel instruments. Dial indicators, which are used primarily in connection with angle-of-attack-sensing devices, provide a progressive indication of the proximity of the stall. However, in order to avail himself of this progressive warning, the pilot must direct appreciable attention to the indicator, perhaps more than most pilots are willing to give to it, particularly in the landing condition.

The auditory forms of warning include the horn and the radio. On airplanes where a horn is already used either in connection with the lowering of the flaps or extension of the landing gear, an additional horn for stall warning may be confusing. The radio-audio warning may not be desirable because of possible interference with radio reception during landing.

The rudder-pedal shaker and the stick shaker are examples of methods of transmitting the warning through feel. The shakers may consist of rotating unbalanced weights or solenoid-operated vibrators. The frequency and amplitude of the shake should be readily distinguishable from those associated with airplane vibration. The amplitude, however, should not be so great as to shake the control surfaces.

EXAMPLES OF STALL-WARNING DEVICES

A few examples of special stall-sensing and angle-of-attack-sensing devices, some of which are commercially available, are illustrated by sketches in figures 2 to 4. The sketches are intended to illustrate a few arrangements and operational characteristics. The drawings are not made to scale. Additional information on stall-warning devices may be obtained in references 1 to 11.

Special Stall-Sensing Devices

Leading-edge orifices.- The device shown in figure 2(a), tested by the Royal Aircraft Establishment, England (reference 1), consists simply of a static-pressure orifice located near the wing leading edge and operates on the basis of the movement of the stagnation point. The orifice is connected to a pressure diaphragm referenced to cockpit static pressure. In operation, as stall is approached, the static pressure at the orifice rapidly increases towards cockpit static pressure as the speed gradually decreases (fig. 1(a)). When the static pressure at the orifice equals cockpit static pressure, a warning of impending stall is provided through the closing of electrical contacts in the pressure diaphragm. The margin of warning in speed above stalling speed is determined by the location of the orifice near the leading edge. In cases where power affects the maximum lift coefficient a second orifice within the propeller slipstream is used.

Leading-edge tab.- The stall-sensing device, illustrated in figure 2(b), consists of a small tab about 1/2 inch square projecting normal to the lower surface very close to the leading edge. The chordwise position of the tab is selected so that at low angles of attack the stagnation point is ahead of the tab and the tab is forced back against a stop. Near stall the stagnation point moves behind the tab with the result that the tab moves forward against a light spring and closes an electrical circuit actuating a stall warning. The margin of warning is adjusted principally through the chordwise location of the tab and also to some extent by adjusting the light restraining spring force on the tab. Another version of the leading-edge tab is a dual-stage device which consists of two tabs located side by side. The chordwise location is selected as with the single unit to provide the initial warning with one of the tabs. The restraining spring force on the second tab is then adjusted to provide a second and more intensive warning at a desired margin.

Spoiler and pitot-static tube.- The device, tested by the National Advisory Committee for Aeronautics (reference 2) and illustrated in figure 2(c), consists of a pitot-static tube mounted on the upper surface of a wing immediately behind a leading-edge spoiler of 4- to 6-inch span. This arrangement may be located near midsemispan as shown in figure 2(c). The total- and static-pressure leads from the pitot-static tube are connected across a pressure diaphragm equipped with electrical contacts. In operation near stall a very limited region of local separation develops immediately behind the spoiler and causes the local impact pressure measured by the pitot-static tube to decrease very rapidly (fig. 1(b)) for small decreases in airplane velocity. The electrical contacts in the pressure diaphragm may be adjusted to close an electrical circuit and give a warning when the local impact pressure

has dropped to a predetermined level. The margin of warning in speed above stalling speed may be changed by altering the span of the spoiler, its leading-edge radius, the height of the tube and its distance from the spoiler, and the spanwise location of the spoiler.

Trailing-edge pitot tube.- The device shown in figure 2(d), tested by the NACA (reference 3), consists of a pitot tube mounted about an inch above the upper surface of a wing near the trailing edge. The pressure lead from the tube is connected to a pressure diaphragm equipped with electrical contacts and referenced to a source of free-stream static pressure. As stall is approached the boundary layer near the trailing edge thickens and finally separates with the result that the total pressure at the tube varies with speed above stall somewhat as shown in figure 1(c). The warning is given when the pressure drops to a predetermined level.

Trailing-edge vane.- The device shown in figure 2(e), tested by United Airlines, Inc., consists of a spring-loaded vane mounted on the upper surface near the trailing edge of the wing. At low angles of attack local dynamic pressure tends to hold the vane parallel to the wing surface. As stall is approached, however, a decrease in local dynamic pressure or separation of flow allows the vane to rotate away from the surface under the action of the spring and to close an electrical circuit which actuates a warning.

Angle-of-Attack-Sensing Devices

Null-pressure devices.- Several typical null-pressure types of angle-of-attack-sensing devices are shown in figure 3. The devices in general consist of a sensing head, cylindrical, spherical, or ellipsoidal in shape, with a pair of orifices or slots usually spaced to provide maximum pressure sensitivity to change in angle of attack. A positioning mechanism is used to rotate the head to maintain zero pressure difference across the orifices. The angular position of the head, transmitted electrically, is the indicated angle of attack.

Free-floating vanes.- Numerous vane types of angle-of-attack-sensing devices differing mainly in detail are available. All operate on the principle of vane alinement in direction of local flow with the indication of angular position transmitted electrically. Some typical angle-of-attack vanes are illustrated in figure 4.

CONCLUDING REMARKS

One of the principal restrictive conditions for most of the stall-warning devices discussed, except perhaps the trailing-edge devices, is icing of the aircraft. The problem here is generally not one of icing of the device but the change in angle of attack and maximum lift coefficient at which stall occurs due to ice formation on the wings. In any of the devices utilizing pressure orifices care must be taken to keep the orifices and any connecting air passages free of foreign matter. Any device external to the airplane should be sufficiently rugged to withstand the usual service handling without affecting the margin of warning. In this connection, since angle-of-attack-sensing vanes tend to be rather delicate because of their very function, particular care must be taken in the handling of such devices. Other common problems associated with either installation or operation of stall-warning devices are the effect of power in the case of propeller-equipped airplanes and the effect of trailing-edge-flap deflection and leading-edge-slat extension.

The form of stall warning should be such as to be readily distinguishable from airplane characteristics or signals associated with conditions other than stall but should not interfere with the pilot's view throught the windshield, divert his attention for too long a time from other essential duties, or interfere with his radio reception.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., January 9, 1952

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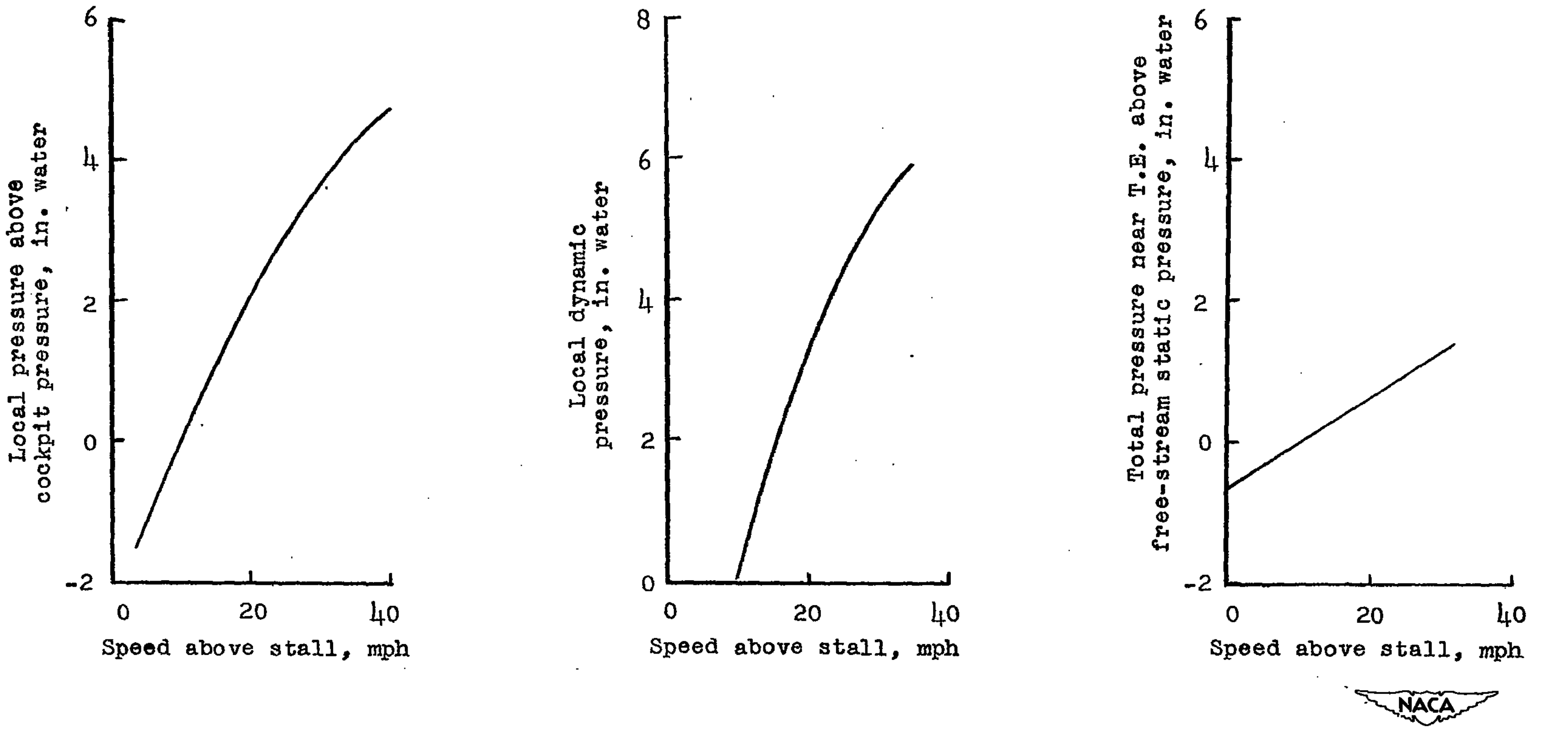
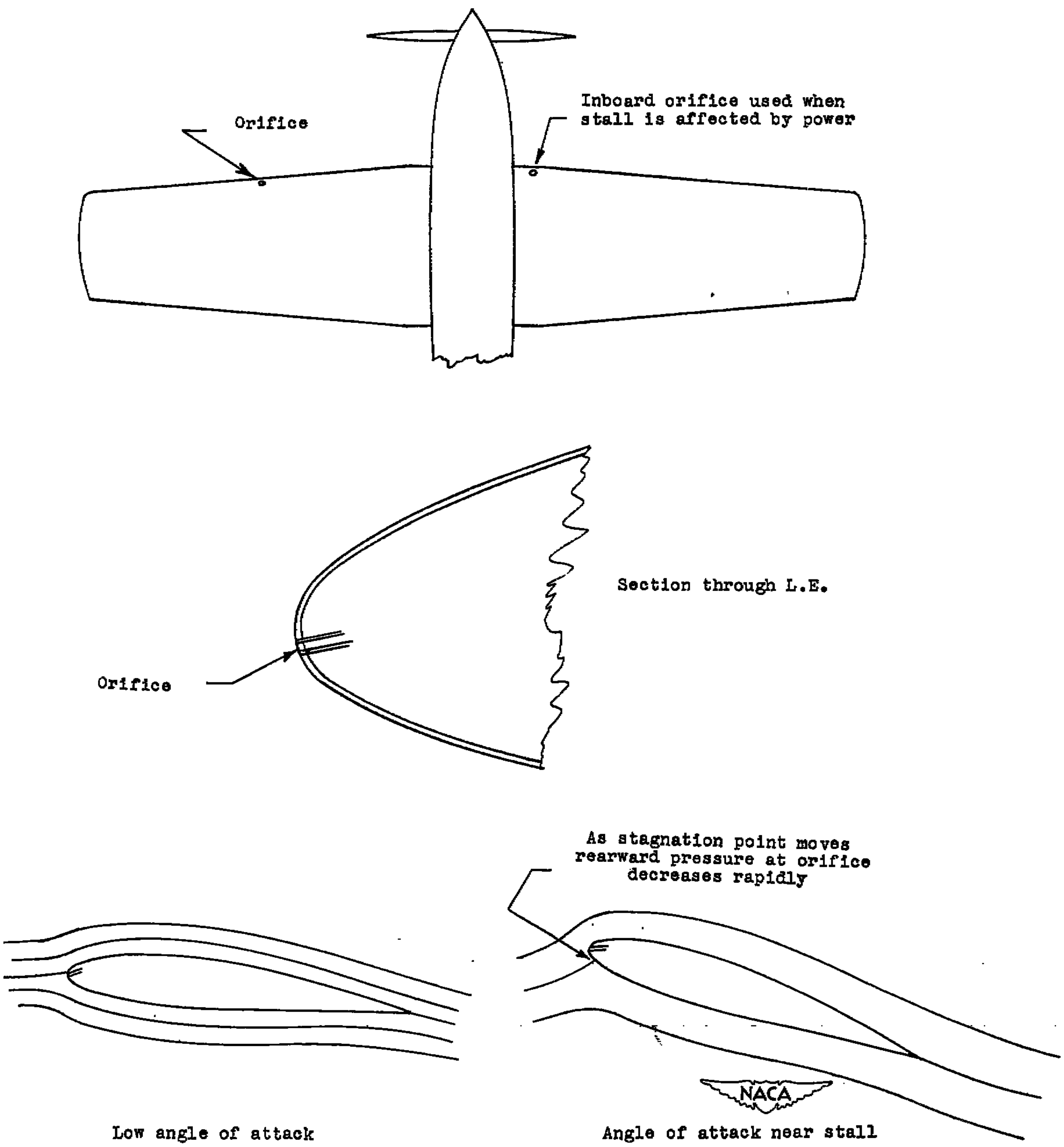


(a) Leading-edge orifice.

(b) Leading-edge spoiler with pitot-static tube.

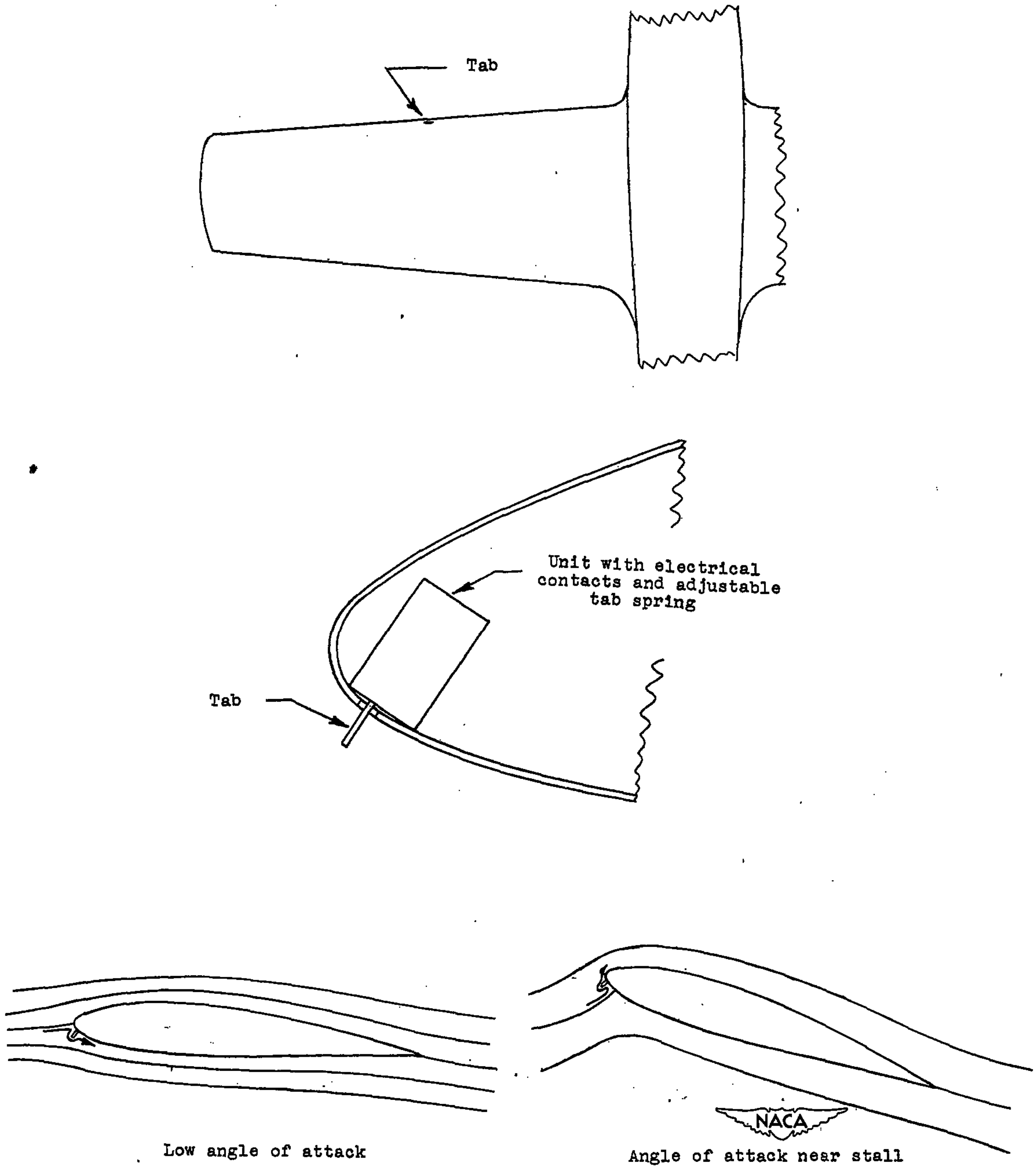
(c) Trailing-edge pitot tube

Figure 1.- Typical variation of local pressures with airspeed above stall for the leading-edge spoiler with pitot-static tube, the leading-edge orifice, and the trailing-edge pitot tube.



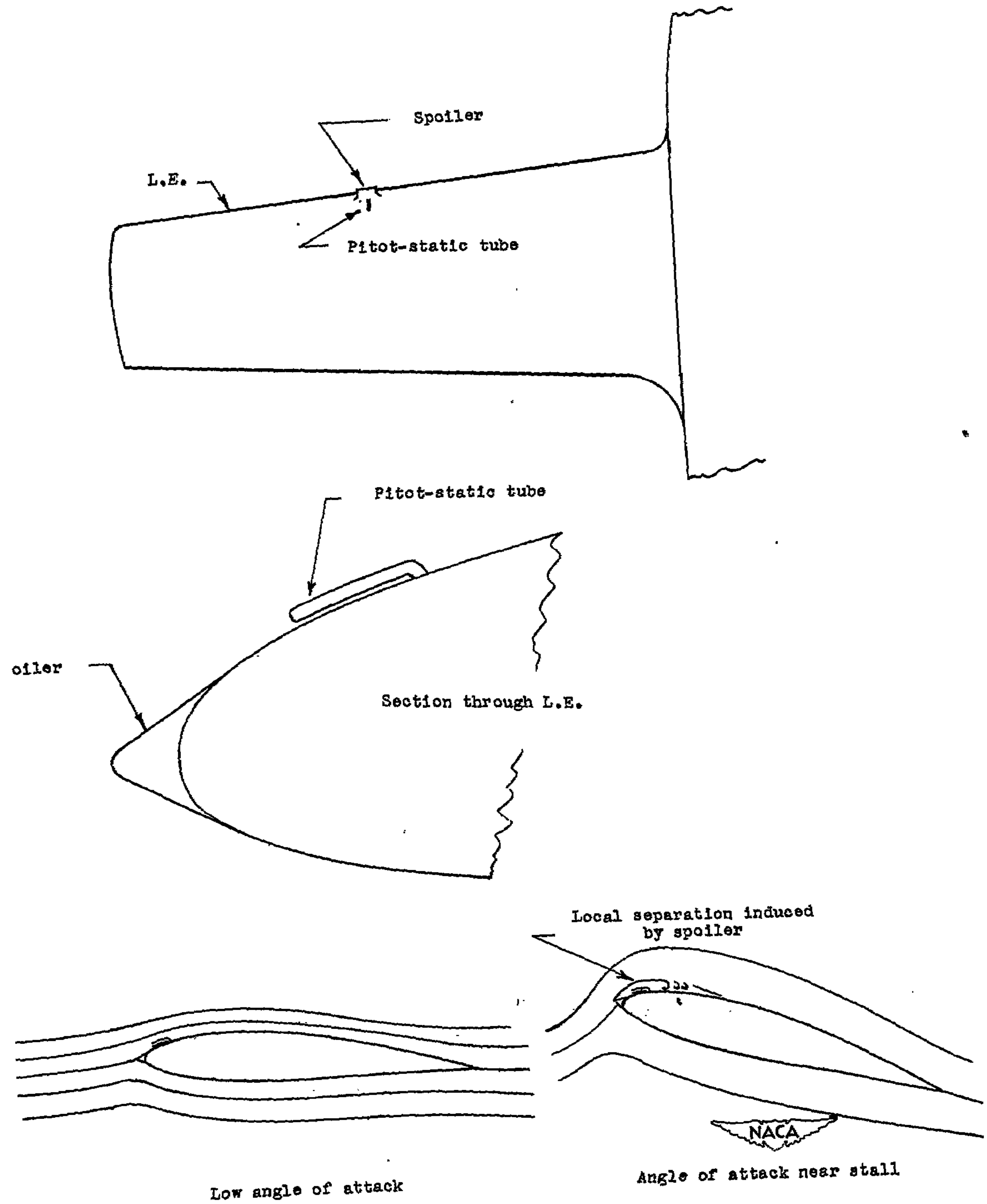
(a) Leading-edge orifice.

Figure 2.- Sketches of special stall-sensing devices.



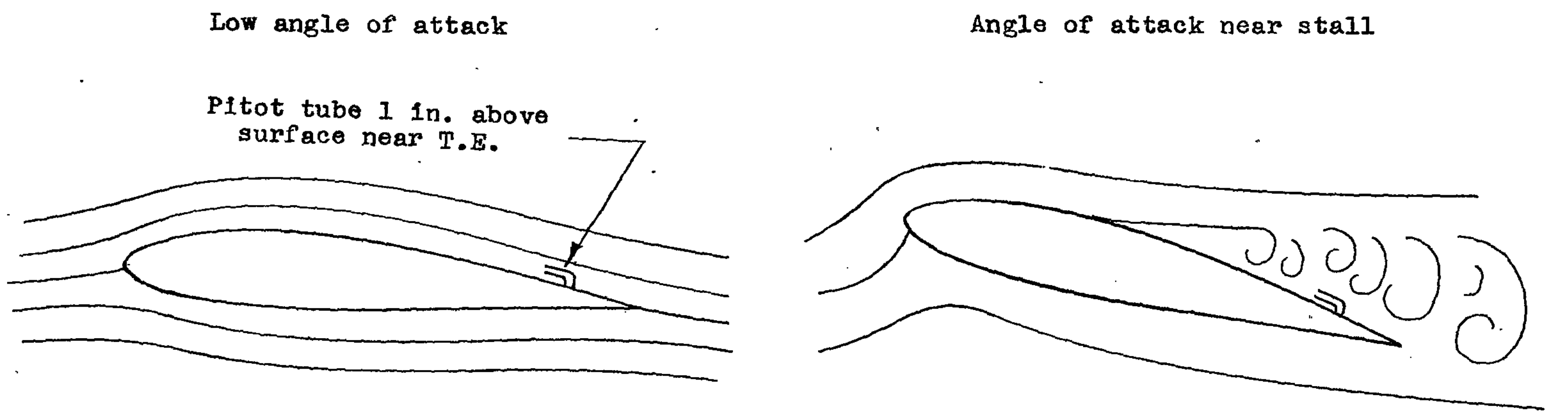
(b) Leading-edge tab.

Figure 2.- Continued.

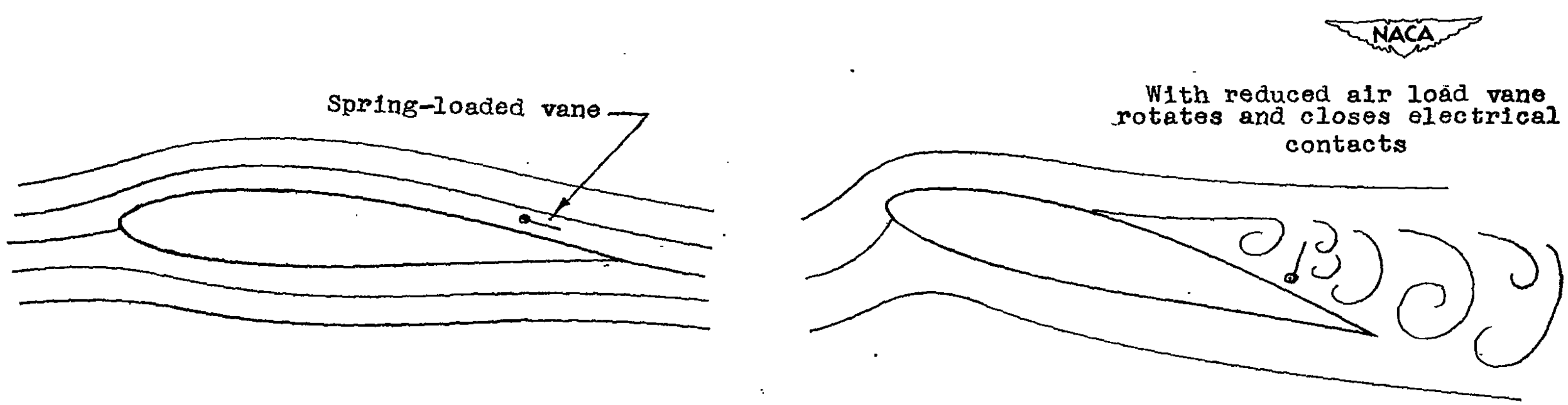


(c) Leading-edge spoiler with pitot-static tube.

Figure 2.- Continued.



(d) Trailing-edge pitot tube.



(e) Trailing-edge vane.

Figure 2.- Concluded.

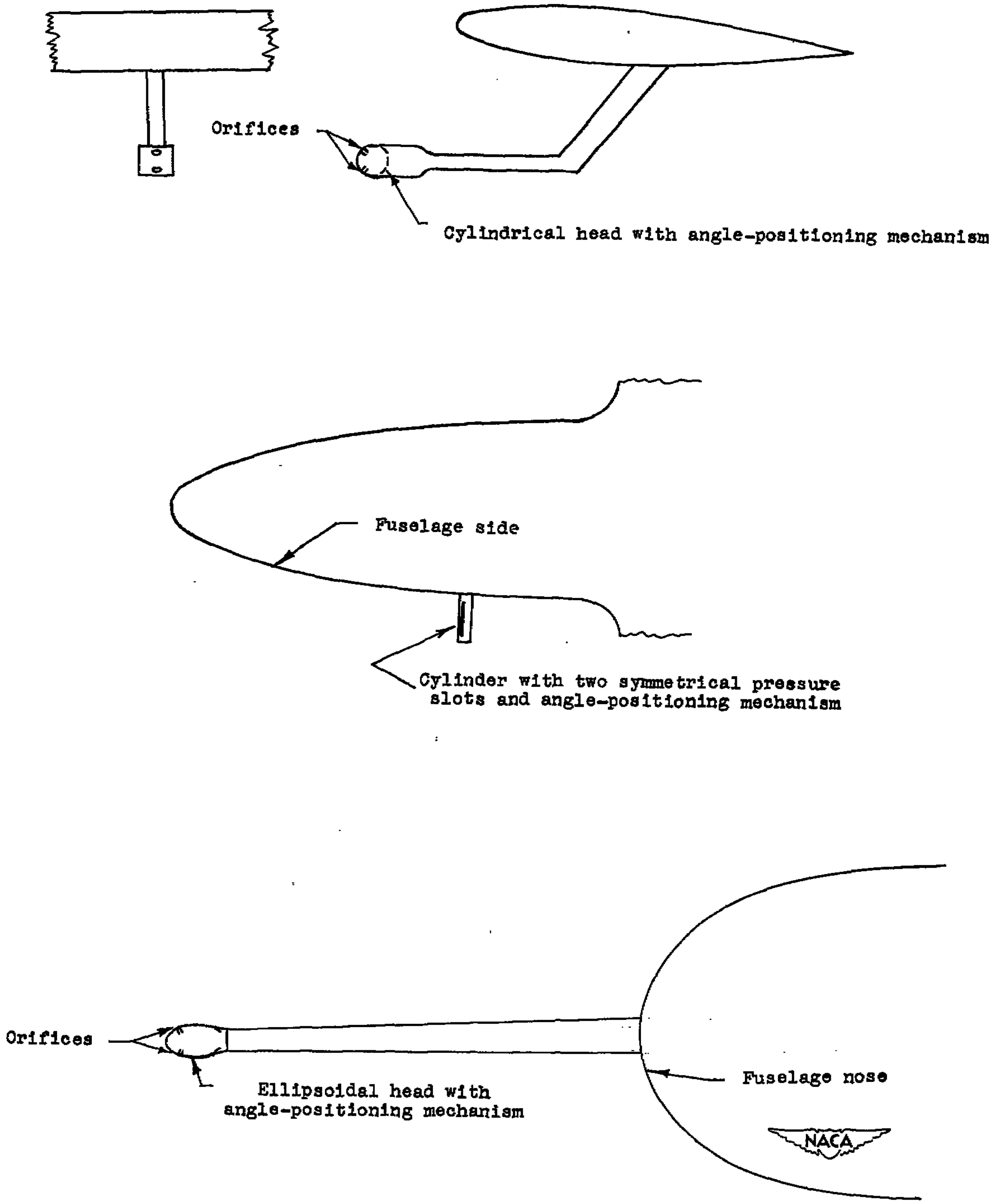


Figure 3.- Sketches of null-pressure types of angle-of-attack-sensing devices.

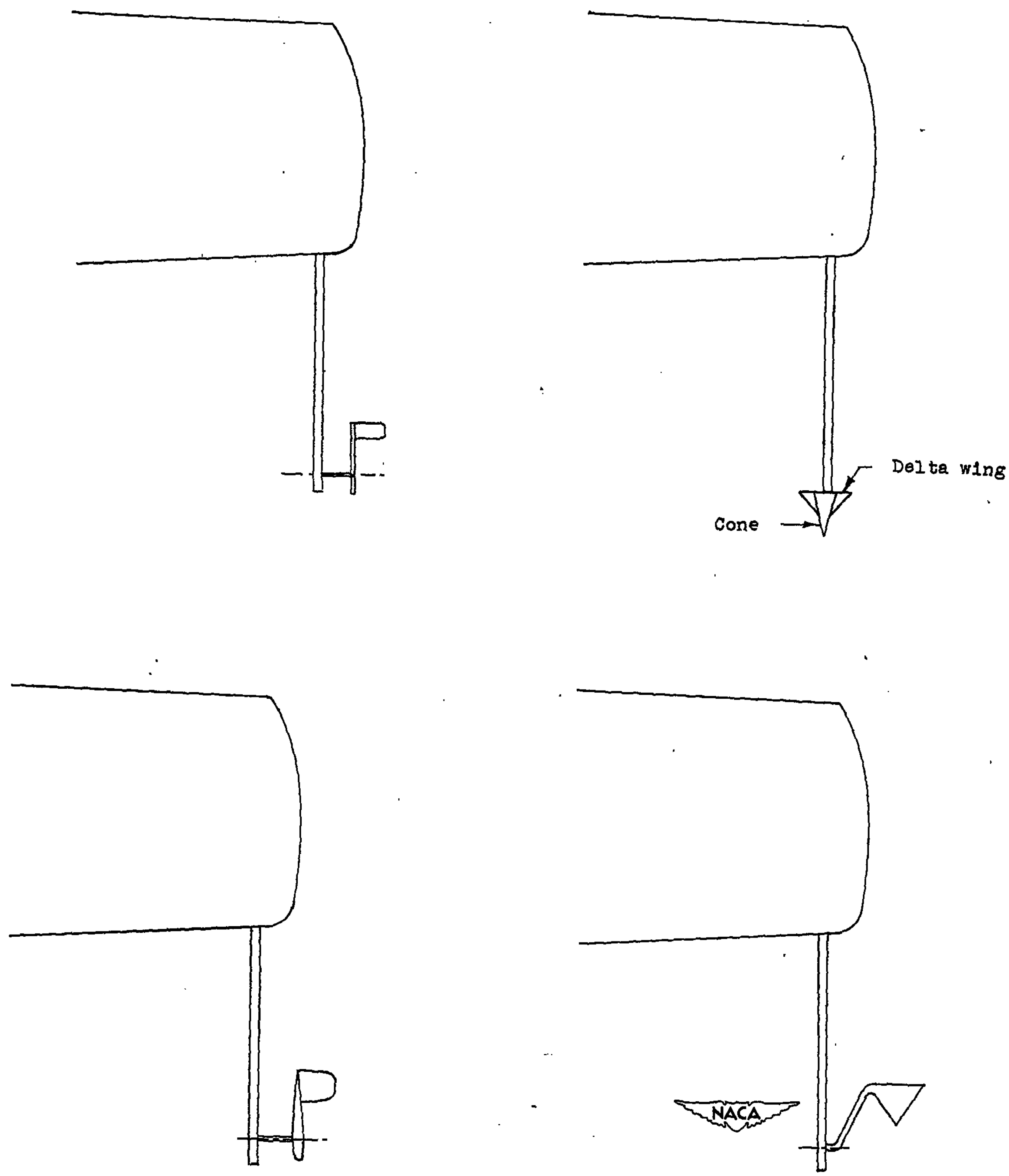


Figure 4.- Sketches of typical free-floating angle-of-attack-sensing vanes.

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